SuperNova/Acceleration Probe (SNAP)

Synopsis

Contacts: Michael Levi: MELevi@lbl.gov, (510) 486-7186, Saul Perlmutter: S_Perlmutter@lbl.gov, (510) 486-5203.

Science Proposal: Online http://snap.lbl.gov/pubdocs/prop.1.6final.pdf.

Collaborating Institutions and Scientists/Engineers:

The SNAP collaboration membership currently consists of 31 physicists, 18 astronomers, and 8 senior engineers drawn from Lawrence Berkeley National Laboratory, University of California, Berkeley, CNRS-IN2P3, Saclay and University Paris VI & VII, University of Michigan, University of Maryland, California Institute of Technology, the Space Telescope Sciences Institute, University of Stockholm, University of Edinburgh, European Southern Observatory, and Instituto Superior Tecnico. We expect further institutions and personnel to participate including: NASA center(s), U.S. Universities, and additional faculty at the above listed institutions.

Description of project and techniques used, list of key technical challenges and new technologies requiring R&D:

SNAP will study thousands of high red-shift supernovae, each with unprecedented precision, using a 2-meter telescope with a one degree wide field-of-view and a unique billion-pixel camera. The SNAP instruments will cover the wavelength range from 400 nm to 1700 nm with spectro-photometry, and can discover and study with equal accuracy supernovae from redshifts of 0.3 up to 1.7. The supernovae will be used as cosmic markers of the scale of the universe over time to construct a history of the universe's growth. Complementary cosmological information will be brought to bear from the resulting wide, deep images; in particular, weak-lensing will be an important part of the science mission.

As a space experiment SNAP will be able to make major advances in our understanding of the dark energy by studying supernovae over a much larger range of redshifts than has been possible with the current ground-based measurements -- and with much higher precision. Detailed measurements of each supernova are necessary not simply to improve statistical uncertainties, but to eliminate or constrain each of the known and postulated systematic uncertainties. In fact the current progress from ground-based measurements will soon reach its systematic-uncertainty limits, beyond which larger sample sizes yield diminishing returns.

A key technical challenge is the manufacture of a wide field instrument with one billion pixels, the detectors and associated electronics, and the operation of the detectors in a space environment. Detectors able to simultaneously achieve the good precision required while operating in a high-radiation environment is an ongoing technology development. The more modest spectrograph, which is key to the classification and characterization of the supernovae is also a technical challenge, requiring high throughput and an integral field unit for accurate spectro-photometry.

Further information about SNAP can be found at the website: http://snap.lbl.gov/.

Description of the science questions that will be addressed and, the science reach:

Supernova studies indicating cosmic acceleration -- based on observations that distant supernovae were dimmer than their redshifts would otherwise suggest -- were first presented in January 1998. This first direct experimental evidence for an accelerating universe, originally interpreted as a positive value of Einstein's Cosmological Constant, can be also be attributed to a new unknown energy (termed "dark energy") that permeates all of space. In the three years since, these results have been reinforced by the recent measurements of the cosmic microwave background (CMB) anisotropy power spectrum when taken together with measurements of the mass density of the universe.

Connecting Quarks with the Cosmos: Eleven Science 'Questions for the New Century', Phase I of the NRC study on the Physics of the Universe notes "Deciphering the nature of dark matter and dark energy is one of the most important goals in the physics of the universe. Resolving both puzzles is key to advancing our understanding not only cosmology but also fundamental physics. The solutions to these problems will cast light not only on the fate of the universe but the very nature of matter, space, and time."

SNAP takes a multi-faceted approach to answering this fundamental challenge. First, a supernova Hubble diagram will be created that is intended to achieve a new level of control over systematic uncertainties, addressing all of the known and proposed sources of possible error. This would be a landmark fundamental measurement, a simple history of our universe's growth over the past 12 billion years. The systematics control will allow several thousand supernovae to contribute to a precision measurement of the major cosmological parameters: Ω_M to ± 0.02 and both Ω_Λ and the universe's curvature to ± 0.05. The goal here is to provide a secure measurement of Ω_M and Ω_Λ that would complement planned precision measurements from the CMB and astronomical studies (note that they would be largely orthogonal to them in the Ω_M -- Ω_Λ plane). The measurement of curvature itself would test our simple cosmological model, by comparing a measurement at redshift $z \sim 1$ to the CMB curvature measurement at $z \sim 1000$.

SNAP's science reach then explores the nature of the dark energy, a fundamentally new entity pervading -- and dominating -- the universe, even more exotic than dark matter itself. The simplest measurement here will be the effective pressure to density ratio, $w=p/\rho$, which SNAP can measure to ±0.05 for a constant-w scenario. However, the practically unconstrained range of dark energy models includes many theories, which can only be differentiated by studying their effect on the universe's expansion over a wide range of redshifts. This is where SNAP's tight control of systematics and statistical uncertainty at each redshift bin from 0 to 1.7 is crucial. Changes in p/ρ (notated w') will thus be measurable to ±0.15, given expected independent constraints on Ω_M at the ±0.04 level. Moreover, the shape of the Hubble diagram, its record of the universe's growth spurts and slowdowns, will differentiate dark energy models -- and might make it possible to characterize the potential-energy curve of a dark-energy scalar field, pointing us to the underlying physics.

While the thorough study of Type Ia supernovae drives the design of SNAP, the resulting instrument will have broad capabilities that will be suitable for complementary measurements, such as the study of dark matter through weak lensing techniques. Weak gravitational lensing can provide a map of the distribution of the dark matter in the universe and with photometric redshifts weak lensing will permit studies of the evolution of structure as a function of redshift. The exquisite image quality and stable point spread function from space dramatically reduces systematic uncertainties. Perhaps most importantly, weak lensing can measure Ω_M, with uncertainties as low as ±0.01--0.02 (for different analysis approaches). This measurement will have little dependence on w, and will play a crucial role in the supernova exploration of w'. It is also expected that a known technique for calibrating Type II supernovae magnitudes will provide a supporting, and independent, Hubble diagram. Finally, SNAP's expected dataset will survey an area of sky several thousand times larger than the Hubble Deep Field, and two magnitudes deeper. The rich range of science that will result from this and other SNAP surveys is well beyond the scope of these two pages.

Within the small handful of available approaches to the study of dark energy, dark matter, and the cosmological parameters, what makes this study of supernovae a particularly attractive opportunity? The primary advantage of the supernovae is that their study has now developed to the point that a detailed list of known and possible systematic uncertainties has been catalogued -- and, more importantly, approaches have been developed to constrain each one.

For example, an approach to the problem of possible supernova evolution uses the rich stream of information that the expanding supernova atmospheres send us in the form of their spectral time series. These data make it possible to study each individual supernova and measure enough of its physical properties to recognize deviations from standard brightness sub-types. Only the *change* in brightness as a function of the parameters classifying a subtype is needed, not any intrinsic brightness. (Supernovae cannot change their brightness in one measured wavelength range without affecting brightness somewhere else in the spectral time series -- an effect that is well-captured by expanding atmosphere computer models.) By matching like to like among the supernova subtypes, the resulting Hubble diagrams have systematic uncertainties at the targeted level.

A series of measurements will be constructed for each supernova that define these systematics-bounding subsets. Many of these measurements (e.g., supernova risetime, early detection to eliminate Malmquist bias, lightcurve peak-to-tail ratio, identification of the Type Ia-defining Si II spectral feature, separation of supernova light from host galaxy light, and identification of host galaxy morphology, etc.) are only achievable in a space environment with low "sky" noise and a very small point-spread-function. A space-based study provides the crucial additional advantage of wide-wavelength-range measurements to constrain alternative dust models.

We believe that the supernova-based measurement is unique in its state of readiness, and its sensitivity to the nature of the universe's dark energy. SNAP provides a comprehensive mission that uses this approach to address this most fundamental science.